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SciVerse ScienceDirect
Physics Procedia 27 (2012) 260 – 263
Physics Procedia

ISS2011

Microstructure and superconducting properties of Bi-2223/Ag tapes fabricated in the variation-temperature-sintering process

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Abstract

The microstructure and superconducting properties of Bi-2223/Ag tapes fabricated in the variation-temperature-sintering process without magnetic field were investigated. The results showed that all tapes variation-temperature-sintered from low temperature to high temperature or from high temperature to low temperature in the first 24 h sintering process showed stronger *c*-axis alignment of the Bi-2223 phase than that isothermal-temperature-sintered. However, the tape processed by the variation-temperature-sintered from low temperature to high temperature showed a low proportion of the Bi-2223 phase. When the starting temperature (above 850℃) of the variation-temperature-sintering from high temperature to low temperature is too high, the proportion of Bi-2223 phase decreases largely. The tape variation-temperature-sintered from 845 to 835℃ for 24 h and then isothermal-temperature-sintered at 835℃ for 96 h showed a strong *c*-axis alignment of the Bi-2223 phase, a high proportion of Bi-2223 phase, and the highest J_c value.

Keywords: Bi-2223; superconductors; texture; variation-temperature-sintering; critical current density

1. Introduction

From a practical point of view, one of the most desired features of the high-temperature superconductors is the ability to transport high electrical current densities (J_c). In addition to an increase of the proportion of Bi-2223 phase during processing, a highly aligned Bi-2223 microstructure is essential for a high J_c value because a low J_c value usually results in a grain boundary weak-coupling problem as well as a random growth habit of the superconducting grains. The microstructure of Bi-based oxide superconductors consists of plate-like grains with the *a*-*b* plane along the flat surface of the platelets. If the grains are aligned by stacking the platelets like a structure of bricks [1], a high J_c can be achieved in the *a*-*b* plane. In order to improve J_c–H behaviour, Dou et al. [2,3] suggested the PFDR (phase formation-decomposition-recovery) method for preparing Bi-2223 Ag-sheathed tape through the use of a short period of melting. The PFDR-processed tape exhibited 3- to 10-fold increase in the J_c at 77 K and in 1 T over the normally processed tapes. A controlled melting (CM) process [4] has been developed on the basis of the PFDR method. At 77 K, the J_c of 36.8 kAcm^{-2} in self-field has been achieved in the CM-processed tapes. It is generally accepted that the mechanical deformation during the tape fabrication can introduce a high degree of texture in the superconducting tape

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 doi:10.1016/j.phpro.2012.03.460

[5-7]. Since Bi-2223 phase texture is largely influenced by the Bi-2212 phase texture, it is essential to improve the Bi-2212 texture during the tape fabrication for the achievement of high J_c Bi-2223 tapes.

The temperature at which Bi-2223 formed was reported to be in the limited range just under the melting temperature [8,9]. The solid isothermal-temperature-sintering is commonly used in fabrication of Bi-2223 superconductors. However, the very slow rate of formation of Bi-2223 phase could result in volatilization of Bi and/or Pb during high temperature sintering, which suggests that the melting temperature varies with the sintering time. Therefore, the variation-temperature-sintering near the melting temperature maybe is a preferable method for preparing Bi-2223 high-temperature superconductors.

In previous works [10,11], we reported our investigation on the microstructure and superconducting properties of the Bi-2223 tapes which were isothermal-temperature-sintered in high magnetic fields. The tape sintered at 840℃ in 10 T showed a strong *c*-axis alignment of the Bi-2223 phase, a high proportion of Bi-2223 phase, and the highest J_c value. Recently [12], we have reported the phase formation and critical current properties of Bi-2223/Ag tapes fabricated in the variation-temperature-sintering process during high magnetic fields. In this work, we report the microstructure and superconducting properties of Bi-2223/Ag tapes fabricated in the variation-temperature-sintering process without magnetic field.

2. Experimental methods

A commercially available co-precipitated powder (Dowa Mining Co. Ltd) with the nominal composition of $Bi_{1.85}Pb_{0.35}Sr_{1.90}Ca_{2.05}Cu_{3.05}O_x$ was packed into cladding Ag tubes. The tubes were subsequently drawn to a diameter of 1.20 mm. Following the drawing, the tubes were rolled into tapes with 0.20 mm thick. These tapes were sintered in following conditions without magnetic field as shown in Fig. 1.: (1) isothermal-temperature-sintering at 835℃ for 120 h, (2) variation-temperature-sintering from 840 to 835℃ for 24 h and then isothermal-temperature-sintering at 835℃ for 96 h, (3) variation-temperature-sintering from 845 to 835℃ for 24 h and then isothermal-temperature-sintering at 835℃ for 96 h, (4) variation-temperature-sintering from 850 to 835℃ for 24 h and then isothermal-temperature-sintering at 835℃ for 96 h, (5) variation-temperature-sintering from 835 to 840℃ for 24 h and then isothermal-temperature-sintering at 840℃ for 96 h. The AC susceptibility measurements were performed with a Sumitomo susceptometer at a frequency of 313 Hz and a current of 50 mA in the temperature range of 20-120 K. The critical current (I_c) was measured at 77 K in self-field using standard four-probe technique with the criterion of $1\mu Vcm^{-1}$. The critical current density J_c was determined from I_c and a cross-section of the oxide core. The proportion of a Bi-2223 phase and grain alignment of the Bi-2223 phase were analyzed by XRD with CuKα radiation. In this study, the degree of texturing of Bi-2223 grains was quantified by an alignment factor *f* defined as

$$f = H(00\underline{1}0)/H(115) \quad (1)$$

The volume fraction of Bi-2223 phase (Q_{2223}) was defined as

$$Q_{2223} = H(00\underline{1}0)/(H(00\underline{1}0) + L(008)) \quad (2)$$

where $H(00\underline{1}0)$ and $H(115)$ are the integrals of the $(00\underline{1}0)$ and (115) peaks of Bi-2223 phase, respectively, and $L(008)$ is the integral of the (008) peak of Bi-2212 phase.

3. Results and discussion

Fig. 2 shows the susceptibility χ' versus temperature plots of the tapes processed by the isothermal-temperature-sintering at 835℃ and the 840-835℃, 845-835℃, 850-835℃, 835-840℃ variation-temperature-sintering in the first 24 h sintering process without magnetic field. It is seen that for all tapes, the changes in susceptibility occur in two steps, i.e. one change at 108 K due to the Bi-2223 phase and the other change at 85 K due to the Bi-2212 phase, are observed. However, the tape processed by 845-835℃ variation-temperature-sintering shows the highest diamagnetism of the Bi-2223 phase, and that processed by 835-840 ℃ variation-temperature-sintering shows the lowest diamagnetism of the Bi-2223 phase.

Fig. 3 shows X-ray diffraction patterns recorded from the tapes processed by the isothermal-temperature-sintering at 835℃ and the 840-835℃, 845-835℃, 850-835℃, 835-840℃ variation-temperature-sintering in the first 24 h sintering process without magnetic field. For the tape variation-temperature-sintered from 845 to 835℃ (Fig. 3c), Bi-

2223 is a major phase, and its alignment factor of the Bi2223 phase (*f*) is 18.5, and hardly any peaks of Bi-2212 phase can be seen. However, for the tapes processed by the isothermal-temperature-sintering (Fig. 3a) and the

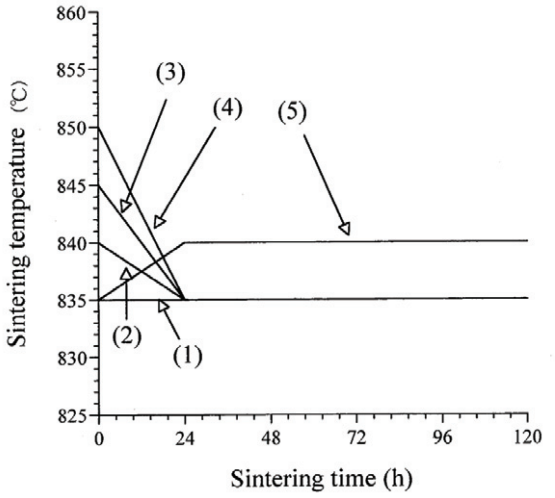

Fig. 1. Temperature profile of the isothermal-temperature-sintering and variation-temperature-sintering processes: (1) isothermal-temperature-sintering at 835℃, (2) variation-temperature-sintering from 840 to 835℃, (3) variation-temperature-sintering from 845 to 835℃, (4) variation-temperature-sintering from 850 to 835℃, (5) variation-temperature-sintering from 835 to 840℃ in the first 24 h sintering and then isothermal-temperature-sintered at 835℃ for 96 h.

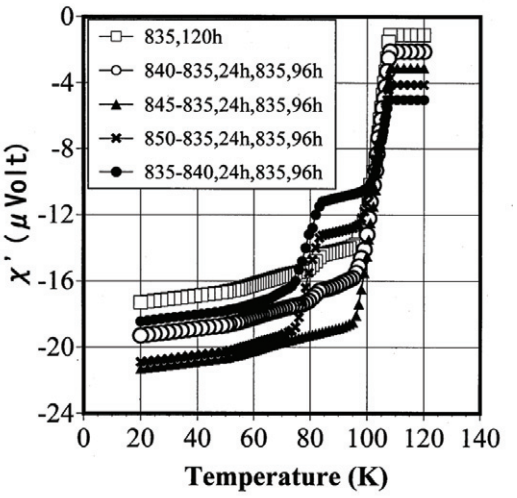

Fig. 2. Susceptibility versus temperature plots of tapes processed by the isothermal-temperature-sintering at 835℃ and the 840-835℃, 845-835℃, 850-835℃, 835-840℃ variation-temperature-sintering in the first 24 h sintering without magnetic field.

840-835℃ (Fig. 3b), 850-835℃ (Fig. 3d) variation-temperature-sintering in the first 24 h sintering process, Bi-2223 is a major phase, coexisting with a small volume fraction of Bi-2212 phase, and their *f*-values are 8.6, 15.5 and 16.5,respectively.This result indicates that highly aligned Bi-2223 phase can be attained by introducing the variation-temperature-sintering from high temperature to low temperature. The tape processed by the 835-840℃ (Fig. 3e) variation-temperature-sintered from low temperature to high temperature shows a low proportion of the Bi-2223 phase in spite of a high *c*-axis alignment factor (17.4).

Fig.4 shows the volume fraction of the Bi-2223 phase of the Tapes. High proportions of Bi-2223 phase can be seen in the tapes variation-temperature-sintered in the first 24 h sintering process from high temperature to low temperature (840-835℃, 845-835℃). However, too high starting temperature (above 850℃) of the variation-temperature-sintering from high temperature to low temperature affects Bi-2223 phase homogeneity as shown in Fig. 4(e).

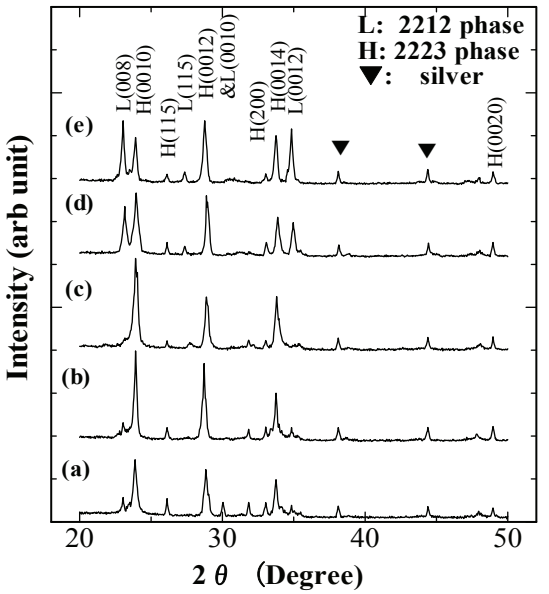

Fig. 3. X-ray diffraction patterns recorded from tapes processed by the isothermal-temperature-sintering at 835℃ (a) and the 840-835℃ (b), 845-835℃ (c), 850-835℃(d), 835-840℃ (e) variation-temperature-sintering in the first 24 h sintering.

Fig. 5 shows the J_c of tapes processed by the isothermal-temperature-sintering at 835℃ (a) and the 840-835℃ (b), 845-835℃ (c), 850-835℃ (d), 835-840℃ (e) variation-temperature-sintering in the first 24 h sintering process without magnetic field. The tapes variation-temperature-sintered from high temperature to low temperature in the first 24 h sintering process show higher J_c value than that isothermal-temperature-sintered and variation-temperature-sintered from low temperature to high temperature in the first 24 h sintering process. The tape variation-

temperature-sintered from 845 to 835℃ in the first 24 h sintering process without magnetic field shows a strong *c*-axis alignment of the Bi-2223 phase, a high proportion of Bi-2223 phase, and the highest J_c value.

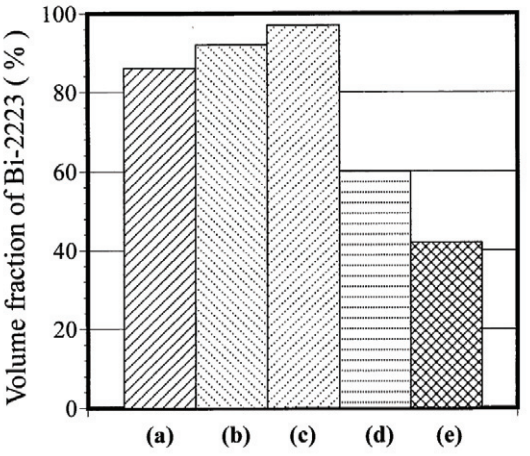

Fig. 4. The volume fraction of Bi2223 phase of the tapes processed by the isothermal-temperature-sintering at 835℃ (a) and the 840-835℃ (b), 845-835℃ (c), 850-835℃ (d), 835-840℃ (e) variation-temperature-sintering in the first 24 h sintering.

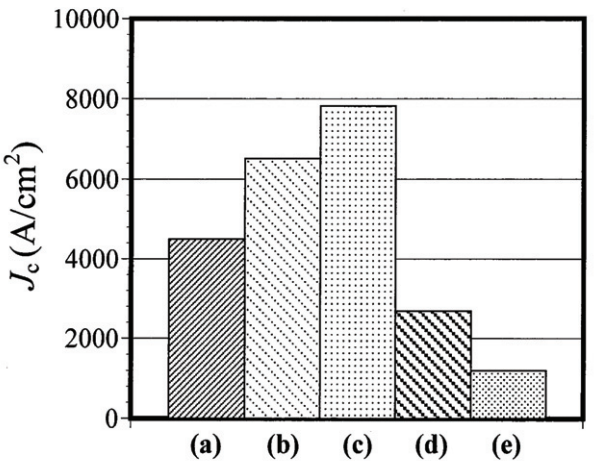

Fig. 5. Critical current densities of the tapes processed by the isothermal-temperature-sintering at 835℃ (a) and the 840-835℃ (b), 845-835℃ (c), 850-835℃ (d), 835-840℃ (e) variation-temperature-sintering in the first 24 h sintering.

4. Conclusion

The microstructure and superconducting properties of Bi-2223/Ag tapes fabricated in the variation-temperature-sintering process without magnetic fields were investigated. The results show that all tapes variation-temperature-sintered from low temperature to high temperature or from high temperature to low temperature in the first 24 h sintering process show stronger *c*-axis alignment of the Bi-2223 phase than that isothermal-temperature-sintered. However, the tape processed by the variation- temperature-sintered from low temperature to high temperature shows a low proportion of the Bi-2223 phase. When the starting temperature (above 850℃) of the variation-temperature-sintering from high temperature to low temperature is too high, the proportion of Bi-2223 phase decreases largely. The tape variation-temperature-sintered from 845 to 835℃ for 24 h and then isothermal-temperature-sintered at 835℃ for 96 h shows a strong *c*-axis alignment of the Bi-2223 phase, a high proportion of Bi-2223 phase, and the highest J_c value.

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